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Enhancing the Detectability of Subtle Changes in Multispectral Imagery Through Real-time Change Magnification

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In this project we adapted the newly developed Phase-Based Video Processing (PBVP) algorithm to enhance the visibility of subtle temporal changes (movement or temperature fluctuations) in multiband (visual, near-, shortwave- and longwave-infrared) imagery while simultaneously reducing dynamic noise. We successfully applied the adapted algorithm to enhance the visibility of small movements in the Visual, Near-Infrared and Thermal (LWIR) bands of multiband video sequences registered by the TNO TRI-band Color Low-light OBServation System (TRICLOBS), and in dynamic short-wave infrared (SWIR) sequences provided by AFRL/711HPW/RHCV. In addition, we applied the method for the early detection of change processes, for the estimation of a person's heart rate from facial videos, and to enhance the visibility of landmines in polarized SWIR sequences. In the course of the project we also developed a simple Power-Logarithm (Pow-Log) histogram modification operator to enhance image contrast, and a new color-to-gray conversion algorithm that retains both the overall appearance and the discriminability of a three channel color image when represented as a single band (grayscale) image.

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Abstract

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1 Objective

The objectives of the project "Enhancing the Detectability of Subtle Changes in Multispectral Imagery Through Real-time Change Magnification" (funded by Grant FA9550-14-1-0069) were to:

- Apply newly developed Phase-Based Video Processing (PBVP) algorithms to enhance the visibility of subtle temporal changes (movement or temperature fluctuations) in details of interest in multispectral imagery while simultaneously reducing dynamic noise.
- Incorporate these algorithms into a multiband image fusion scheme.
- Demonstrate the practical value of the newly developed algorithms by applying them to a set of example videos.

2 Results

In this section we will first give an overview of the results of applying the PBVP method to multispectral imagery (the main goal of this project). This is followed by an account of some additional supporting algorithms (an adaptive contrast enhancement algorithm and a color-to-grayscale transform) that were developed in the course of this project.

2.1 Motion enhancement

Recently a new method (called Phase-Based Video Processing or PBVP) was introduced to enhance the visibility of low-amplitude temporal (color or location) changes in a standard video sequences (Wadhwa et al., 2013). The method does not need feature tracking or optical flow computation to amplify time-varying events, but merely magnifies temporal phase changes through hierarchical spatio-temporal filtering. A spatially oriented complex-valued multi-scale (steerable pyramid: Simoncelli & Freeman, 1995) decomposition, followed by temporal filtering is applied to the input frames. The complex phase variations in the resulting signal are then either *amplified* to reveal any hidden time-varying information, or *attenuated* to remove distracting dynamic noise. The method is robust, supports large magnification factors, operates locally and is not sensitive to noise.

In this study we adapted the PBVP method to enhance the visibility of low-amplitude temporal events (i.e., of subtle changes) in multispectral imagery.

The PBVP method can also be applied to reduce dynamic noise by attenuating phase variations in the complex steerable pyramid transformed input signal.

Finally, it is in principle, possible to selectively enhance or attenuate temporal events at different spatio-temporal scales. Thus, movement of large (e.g., vehicles) and small (e.g., branches or leaves) details, or high and low temporal frequencies (e.g., trembling leaves and swaying trees) may be selectively enhanced or attenuated.

PBVP enhancement can be applied to individual bands of a dynamic multispectral image sequence. After PBVP enhancement , the individual bands can be fused into a single dynamic motion sequence. Since the PBVP enhancement technique employs a steerable pyramid filter scheme, which is highly suitable to fuse multispectral imagery (Koren et al., 1995; Liu et al., 2001), it can in principle be incorporated into a real-time image fusion framework, thus integrating the enhancement and fusion into a single scheme (Toet et al., 1989; Toet, 1990).

2.1.1 Motion enhancement of TRI-band Color Low-light OBServation System (TRICLOBS) video sequences

PBVP enhancement was successfully applied to enhance the visibility of small movements in the Visual, Near-Infrared and Thermal (LWIR) bands of multiband TRICLOBS video sequences.

One of the examples includes a TRICLOBS movie of a row of persons, one of which had an elevated heart rate and was panting (he had been running just before the video was recorded). In the original movie it is not possible to visually distinguish the person with the elevated heart rate. In the PBVP processed movie this person is clearly distinguishable due to the enhanced movements of his chest.

Another example includes a TRICLOBS movie of some tall trees. While these appear stationary in the original footage, they are clearly swaying in the wind in the PBVP enhanced version of this movie.

The PBVP motion enhancement appeared to work well on all the individual TRICLOBS image bands. After enhancement, the individual bands can be combined and color-remapped to obtain a dynamic image sequence with a natural color appearance (Hogervorst et al., 2006; Hogervorst & Toet, 2010).

2.1.2 Motion enhancement of SWIR video sequences

PBVP enhancement was also successfully applied to enhance small movements in dynamic short-wave infrared (SWIR) imagery provided by Dr. Alan Pinkus (AFRL/711HPW/RHCV). The method was able to significantly enhance minor movements of fingers, chest, eyes and arms in dynamic SWIR sequences of a person who was appeared static.

2.1.3 Motion enhancement of time-lapse imagery

We also tested the capability of the PBVP enhancement for the early detection of change processes (e.g., diffusion of waste material, onset of fires, onset of processes like disintegration or decomposition). The idea to PBVP enhance dynamic imagery of the onset of such processes and play the enhanced movies in a looping mode to enable visual detection of processes that would otherwise go unnoticed. This was only partly successful. The problem is that these processes are typically restricted to a small part of the image in their early stages. As a result, there are an insufficient number of image pixels showing a change and the method is ineffective. Only when these processes are in an advanced stage does the method enhance their amplitude, but by then they are already clearly visible in video sequences that are not enhanced.

2.2 Heart rate estimation from facial videos

The enhancement of temporal color variations in facial videos enables the extraction of a person's heart rate (since this corresponds to the frequency of the facial color variations). In an experiment we simultaneously measured ECG and recorded visual imagery. We found a match between the heart rate derived from ECG and from the color fluctuations in the skin, indicating that the heart rate can be derived from visual imagery.

2.2.1 Visualization of landmines through polarized image sequence enhancement

Previously, a 3-5 μm (mid-wave infrared) Radiance high-speed camera in combination with a rotating polarization filter was used to register dynamic imagery of landmines that were left undisturbed for long period in a field (Cremer, 2003). As a result the landmines were largely covered with tall grass (i.e., they were obscured from direct vision) and they were in a cluttered environment (vegetation, rocks, etc.). The idea is that the representation of the landmines in the IR sequences will show a temporal intensity fluctuation that differs from the clutter elements in their background. Deployment of PBVP motion enhancement to the abovementioned dynamic video sequences did indeed make small differences in the temporal variation of the profiles of the landmines more salient, thus possibly enabling the detection of landmines that would otherwise go unnoticed.

2.3 Adaptive contrast enhancement

A simple Power-Logarithm (Pow-Log) histogram modification operator was developed to enhance infrared (IR) image contrast (Toet & Wu, 2015). The algorithm combines a Logarithm (Log) operator that smooth the input image histogram while retaining the relative ordering of the original bins, with a Power (Pow) operator that restores the smoothed histogram to an approximation of the original input histogram. Contrast enhancement is achieved by using the cumulative distribution function of the resulting histogram in a standard lookup table based histogram equalization procedure. The method is simple and independent of image content and, unlike most existing contrast enhancement algorithms, does not suffer from the occurrence of artifacts, over-enhancement, and unnatural effects in the processed images. The method can be applied both in a Direct Pow-Log (DPL) and in an Iterative Pow-Log (IPL) mode.

Objective (computational) and subjective (visual) evaluation studies using a wide range of different IR input images showed that DPL and IPL both significantly enhance image contrast while retaining the overall image structure and preserving the perceptibility of small details and targets (Toet & Wu, 2015). DPL retains image structure slightly better than IPL, while IPL enhances contrast slightly more than DPL. Experimental results proved that the proposed method is a robust and efficient technique for effective IR image contrast enhancement.

Using a wide range of different color input images it was shown that the power-logarithm contrast enhancement method can also be applied to regular color images (e.g., photographs), and achieves appreciable contrast enhancement on under diverse lighting conditions (Toet & Wu, 2014; Wu & Toet, 2014a). Moreover, performance comparisons with several state-of-the-art contrast enhancement algorithms showed that the method performs comparably or even better than computationally more complex and time consuming methods.

2.4 Color-to-grayscale conversion

We developed a new color-to-gray conversion algorithm that retains both the overall appearance and the discriminability of the three channel (in the rest of this report denoted as RGB) input image (Wu & Toet, 2014b). Actually, the input image may consist of more than three channels, which need not correspond to realistic colors but may contain input from imaging sensors operating in different spectral bands (even outside the visual spectrum). The algorithm uses a weighted pyramid image fusion scheme to blend the R, G, and B color channels of the input image into a single grayscale image. First, a scalar-valued weight map is computed for each of the R, G, and B color channels. This weight map is composed of several simple visual quality metrics and serves to preserve only the most salient (informative) visual details from each of the input color channels in the final grayscale image. Next, a multiresolution weight map is constructed for each channel by applying a Gaussian pyramid transform to its corresponding weight map. The three multiresolution weight maps are then normalized such that they sum to one for each pixel. Then, the R, G, and B color channels of the input image are decomposed into Laplacian pyramids, which basically contain band-pass filtered versions at different spatial scales. Finally, after multiplication of these Laplacian pyramids by their corresponding Gaussian pyramid weight maps and summation, the final grayscale converted image is obtained by reconstructing the resulting pyramid. The method is straightforward and automatic (requires no user interaction), has limited complexity, and performs at least as well as the best performing state-of-the-art color-to-grayscale conversion algorithms. The main contribution of this method is that it formulates the color-to-grayscale conversion problem as a visual saliency weighted multi-scale channel fusion scheme, to achieve a grayscale representation that optimally represents the information contained in each of the channels of an RGB color image.

3 Deliverables

3.1 Software and imagery

The algorithms that were used and developed in the course of this project were programmed in Matlab 2012a. All Matlab code, images and video sequences used in this study will be provided to Dr. Alan Pinkus (AFRL/711HPW/RHCV).

3.2 Publications

The following publications resulted directly from this study and all contain the appropriate acknowledgments to Grant FA9550-14-1-0069 :

- Toet, A. & Wu, T. (2014). Efficient contrast enhancement through log-power histogram modification. Journal of Electronic Imaging, 23(6), 063017. DOI 10.1117/1.JEI.23.6.063017.

- Toet, A. & Wu, T. (2015). Infrared contrast enhancement through log-power histogram modification. Journal of Pattern Recognition Research, 10(1), 1-23. DOI 10.13176/11.617.

- Wu, T. & Toet, A. (2014a). Efficient contrast enhancement through log-power histogram modification. In D.A. Huckridge & E. Reinhard (Eds.), Electro-Optical and Infrared Systems: Technology and Applications, SPIE-9249-26 (pp. 1-14). Bellingham, WA, USA: SPIE.

- Wu, T. & Toet, A. (2014b). Color-to-grayscale conversion through weighted multiresolution channel fusion. Journal of Electronic Imaging, 23(4,. article no. 043004), 1-6. DOI 10.1117/1.JEI.23.4.043004.

4 Concluding Remarks

All results and the deliverables will be presented to Dr. Alan Pinkus (AFRL/711HPW/RHCV) and his colleagues during a Windows on Science visit by Dr. Alexander Toet and Dr. Maarten Hogervorst to Wright-Patterson AFB, OH , from 27-29 May 2015.

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Toet, A. & Wu, T. (2015). Infrared contrast enhancement through log-power histogram modification. *Journal of Pattern Recognition Research, 10(1),* 1-23. DOI 10.13176/11.617

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